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Raman studies of acoustical phonons in strained hexagonal GaN/AlGaN superlattices

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Abstract. We report the first experimental observation of folded acoustical modes in strained hexagonal GaN/$Al_xGa_{1-x}N$ superlattices by Raman scattering. The dispersion of LA phonon branch was determined by using different scattering configurations. It was found that the zone-center gap of folded phonon branch is beyond the instrumental resolution (≈ 0.5 cm^{-1}). The sound velocity for GaN/$Al_xGa_{1-x}N$ SL with Al content $x = 0.28$ was found to be 8410 m/s.

1. Introduction

GaN, AlN and $Al_xGa_{1-x}N$ alloys are promising materials for realization of optoelectronic devices operating in blue and green spectral region. During last few years GaN/AlN and GaN/$Al_xGa_{1-x}N$ short-period superlattices (SLs) were under intensive investigation, but only a few reports were devoted to studies of lattice dynamics in SLs. The available experimental data are mainly concerned with the long wave optical lattice vibrations in these structures [1, 2]. To our knowledge, no data on Raman scattering in the region of acoustical phonons in GaN based SLs have been published. The formation of SL induces a folding of the Brillouin zone in the growth direction, which result in appearance of new Raman active phonon modes. The investigation of folded acoustical modes can provide information on the SL parameters, sound velocity for average compound of SL, and dispersion of acoustical phonons [3]. The goal of this work is to study the Raman scattering in the region of folded acoustical modes in strained hexagonal GaN/$Al_xGa_{1-x}N$ SLs.

2. Sample characterization

The structures were grown by MOCVD and consisted of 500–1000 nm GaN or $Al_xGa_{1-x}N$ buffer layer grown directly on sapphire substrate followed by SL. The period of SLs was varied from 5 nm to 40 nm. The GaN well and $Al_xGa_{1-x}N$ barrier thickness were equal and the total thickness of all SLs was close to 3 μm. The SLs have been characterized by X-ray diffraction, electron probe microanalysis and atomic force microscopy (AFM). X-ray diffraction rocking curves for (0002) reflection measured in $\Theta - 2\Theta$ scan mode demonstrate well resolved satellite pattern indicating a well defined period d_p (Fig. 1(a)). By fitting of simulating rocking curves to the experimental ones the SL period, Al content in the alloy and the strain of the alternative layers were obtained.

We have obtained image of SL layers by using AFM P4-Solver (produced by NT-MDT, Russia) operating in local elasticity mode (Fig. 1(b)). The contrast in this picture arises

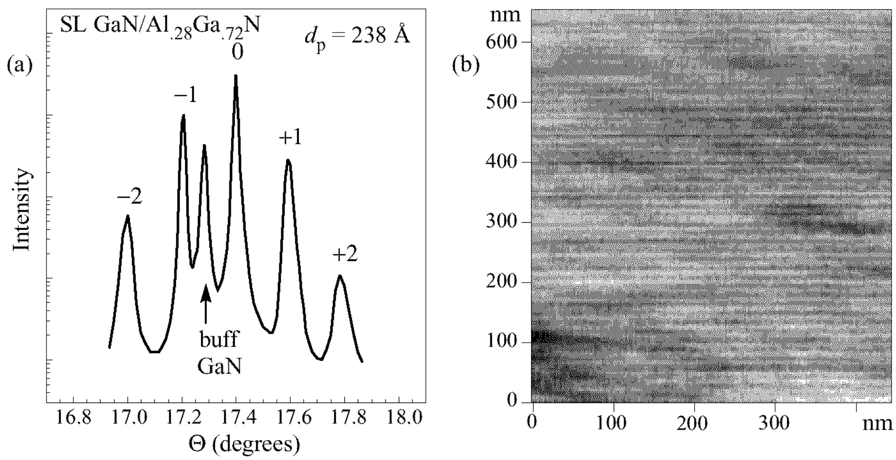

Fig. 1. (a) $\Theta - 2\Theta$ diffraction curve of (0002) reflection for SL with the period $d_p = 238$ Å; (b) AFM-image of cleavage surface relief obtained from GaN/Al$_x$Ga$_{1-x}$N SL ($d_p = 128$ Å).

from extremely small variations of relief due to the different sign of strain in the SL layers. SLs parameters obtained from X-ray and AFM measurements agree well with growth calibrations.

3. Experimental results and discussion

Raman spectra of GaN/Al$_x$Ga$_{1-x}$N SLs were measured in backscattering and 90-degree configurations at room temperature and at 100 K, with an Ar$^+$ laser ($\lambda = 488$ nm) excitation. Figure 2(a) shows Raman spectra in the acoustical frequency range, obtained for some of the samples in $z(xx)\bar{z}$ configuration. Here, the Porto's notation is used for scattering geometries with z to be parallel to the wurtzite c axis, and x and y to be mutually orthogonal and oriented in arbitrary manner in the substrate plane. The Raman spectra of all samples contain the doublets of narrow lines. The shift of doublets toward the exciting line with

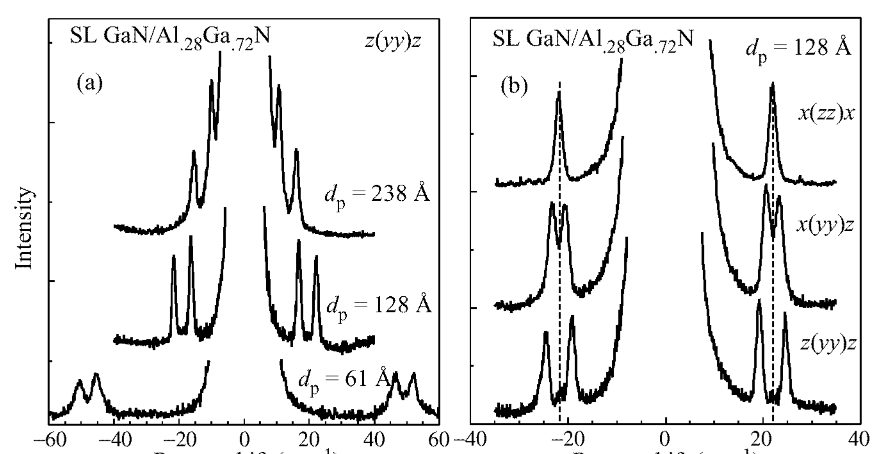

Fig. 2. (a) Raman spectra of SLs with different periods at $T = 300$ K; (b) Raman spectra of GaN/Al$_x$Ga$_{1-x}$N SL obtained in different scattering configurations at $T = 300$ K.

the increase of SL-period is inherent for the folded acoustical phonons. The Raman shift $\Delta\omega^{\pm}_{n,q_z}$ of the doublet lines is given by

$$\Delta\omega^{\pm}_{n,q_z} = \omega_{n,0} \pm q_z s. \tag{1}$$

Here $\omega_{n,0} = 2\pi ns/d_p$ is a frequency of the folded zone center LA-phonon, q_z is the phonon wave vector projection in the folding direction, s the LA sound velocity for averaged compound of SL, and $n = 0, 1, 2 \ldots$. The value of s is different for SL's with abrupt interface [4] and structures with smooth modulation [5].

We have evaluated the sound velocity from the Raman data presented in Fig. 2(a). The data for different SLs are close and the averaged velocity is equal to 8410 m/s for $x = 0.28$. Experiments performed in different configurations allowed us to vary the phonon wave-vector from its maximum value in backscattering geometry along c-axis to almost zero for the in-plane scattering and thus to determine the dispersion curves of LA-phonon branch in SLs. We used three scattering configurations (Fig. 2(b)). The backscattering configuration provides the wave vector equal to $2k_{\text{photon}}$. The 90-degree configuration $z(xx)y$ reduces the z-projection of phonon wave vector to $q_z = k_{\text{photon}}$. The further decrease of phonon wave vector is reached for the in-plane backscattering configuration $x(zz)\bar{x}$ which leads to vanishing q_z. Doublets with the line spacing depending on the value of q_z were found in Raman spectra for $z(xx)\bar{z}$ and $z(xx)y$ configurations. However, in $x(zz)\bar{x}$ geometry only the single line at the position corresponding to the center of the doublets was observed. Since the first observation of folded acoustical phonons in Raman scattering [6] the behavior of modes at vanishing q_z was a subject of high interest. The zone center gap between folded acoustical branches provides an information about the SL parameters [3, 5]. Our results show that the zone-center gap of folded phonon branch for GaN/Al_xGa_{1-x}N SLs is beyond the instrumental resolution (≈ 0.5 cm^{-1}), which suggests the smooth modulation of SLs studied.

4. Summary

The Raman scattering from folded acoustical modes have been studied in strained hexagonal GaN/Al_xGa_{1-x}N SLs for the first time. The dispersion of LA phonon branch along the c-axis was determined by using different scattering configurations. It was found that the zone-center gap of folded phonon branch is beyond the instrumental resolution (≈ 0.5 cm^{-1}). The sound velocity for GaN/Al_xGa_{1-x}N SL with Al content $x = 0.28$ was estimated from Raman data. Study of dependence of LA sound velocity on Al content in GaN/Al_xGa_{1-x}N SL is in progress.

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